Getting More From Wind

Wind-To-Hydrogen Demonstration Project

A Collaboration Between Xcel Energy and the National Renewable Energy Laboratory

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Introduction

- **Initial interest prompted by January 2003 State of the Union Address**
  - **Reliance on foreign oil having impact on national security – Largest user: Transportation**
  - **Initially, $1.4 billion in research funding for hydrogen and fuel cell technologies over 5 years**
- **Energy Policy Act of 2005 authorizes even more**
- **Secretary of Energy tasked to co-develop hydrogen infrastructure in parallel with fuel cell vehicles**
- **Electric utilities will have a major role in the *hydrogen-electric* infrastructure**

H2-Electric Economy Benefits

- **Energy security - primary driver**
  - **Dependence on foreign oil**
  - **Oil production projected peak within 20 years**
- **Environmental benefits (assuming more carbon-free** (e.g., renewable, hydro and nuclear) **power and carbon sequestration)**
- **Potential enabler for more distributed energy system**

Hydrogen Concepts

- **Hydrogen is an energy carrier (*energy "currency"*), not a primary source of energy**
- **When hydrogen is burned in air the main product is water. The key advantage of hydrogen is that carbon dioxide (CO2) is not produced when hydrogen is burned**
- **1 kilogram of hydrogen ≈ 1 gallon of gasoline**
- **Fuel cells are about twice as efficient as gasoline internal combustion engines – Thus, only half the amount of hydrogen would be needed to drive the same distance**

Milestone: December 2, 2004

Xcel Energy CEO, Dick Kelly requests development of a hydrogen demonstration project

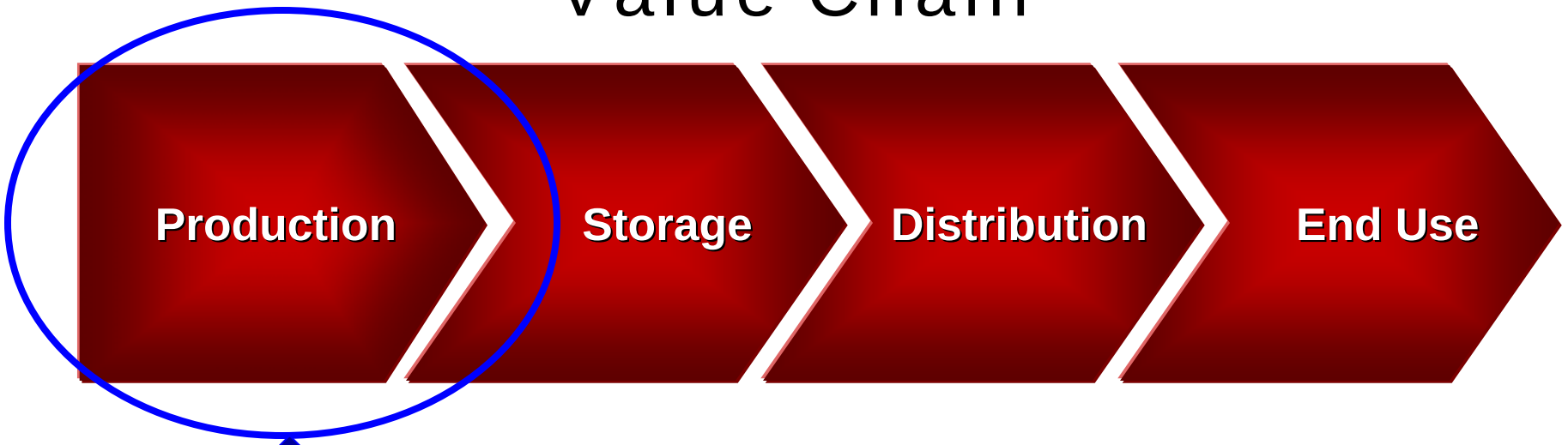
Approach

- **Collaboration**
- **Technical Brainstorming**
- **Focusing**
- **Economic Analyses**
- **Go/No-Go Decision**

Project Collaboration

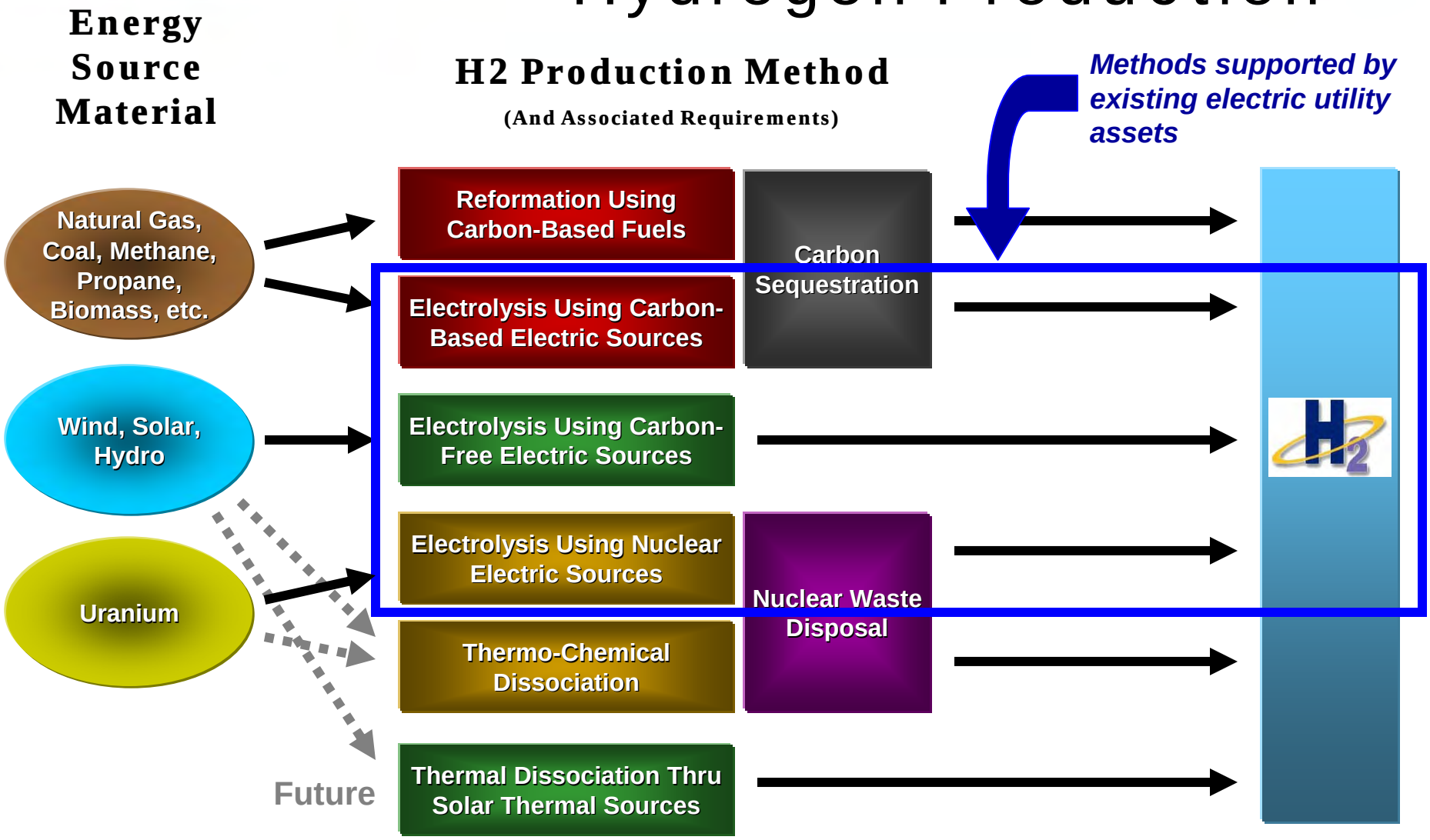
Collaborators (*Date Joined*)
NREL (*12/04*)
DOE Headquarters (*12/04*)
EPC, LLC (*12/04*)
EPRI (*12/04*)
Colorado State University (*1/05*)
University of Minnesota (*7/05*)
Colorado Governor's Office of Economic Development (*9/05*)
City of Fort Collins (*9/05*)

Hydrogen-Electric Economy Value Chain

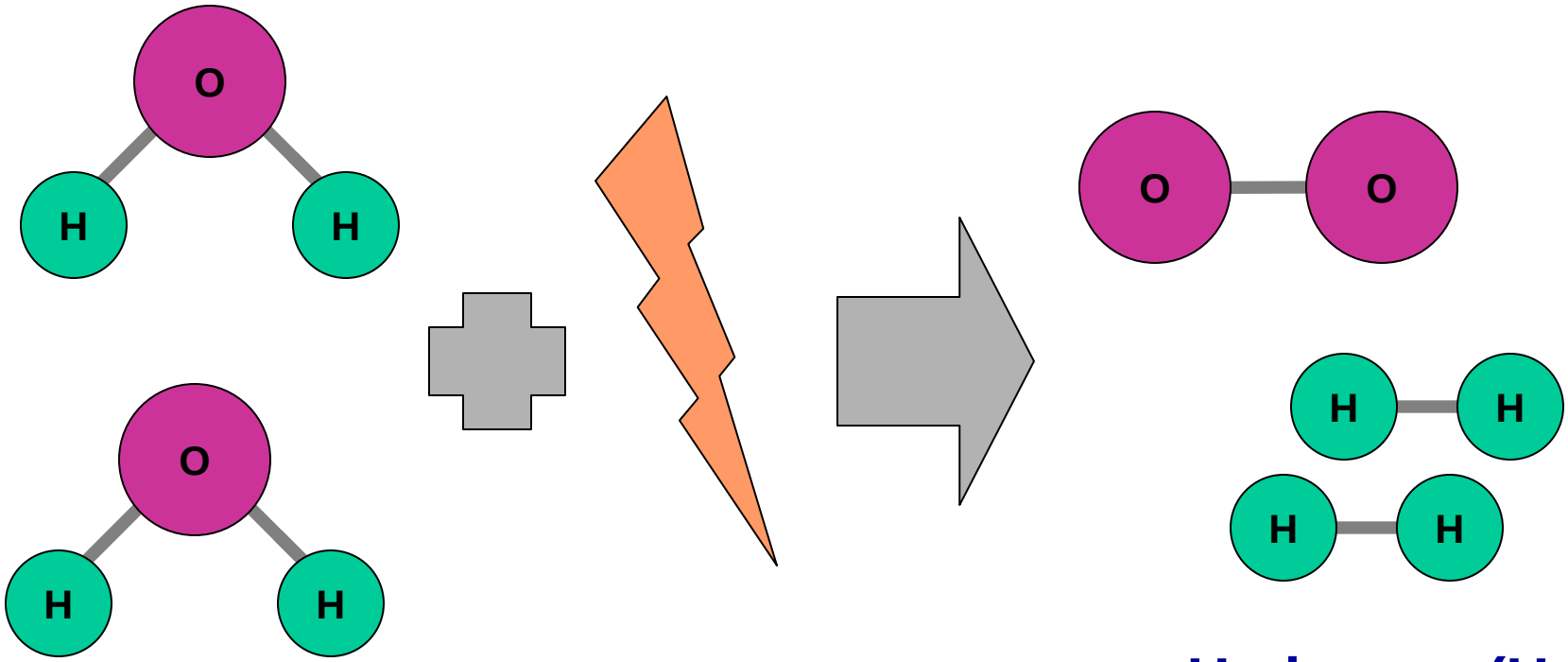


Best area for early contributions to hydrogen-electric infrastructure by electric utilities

Hydrogen Production



How Does Electrolysis Work?

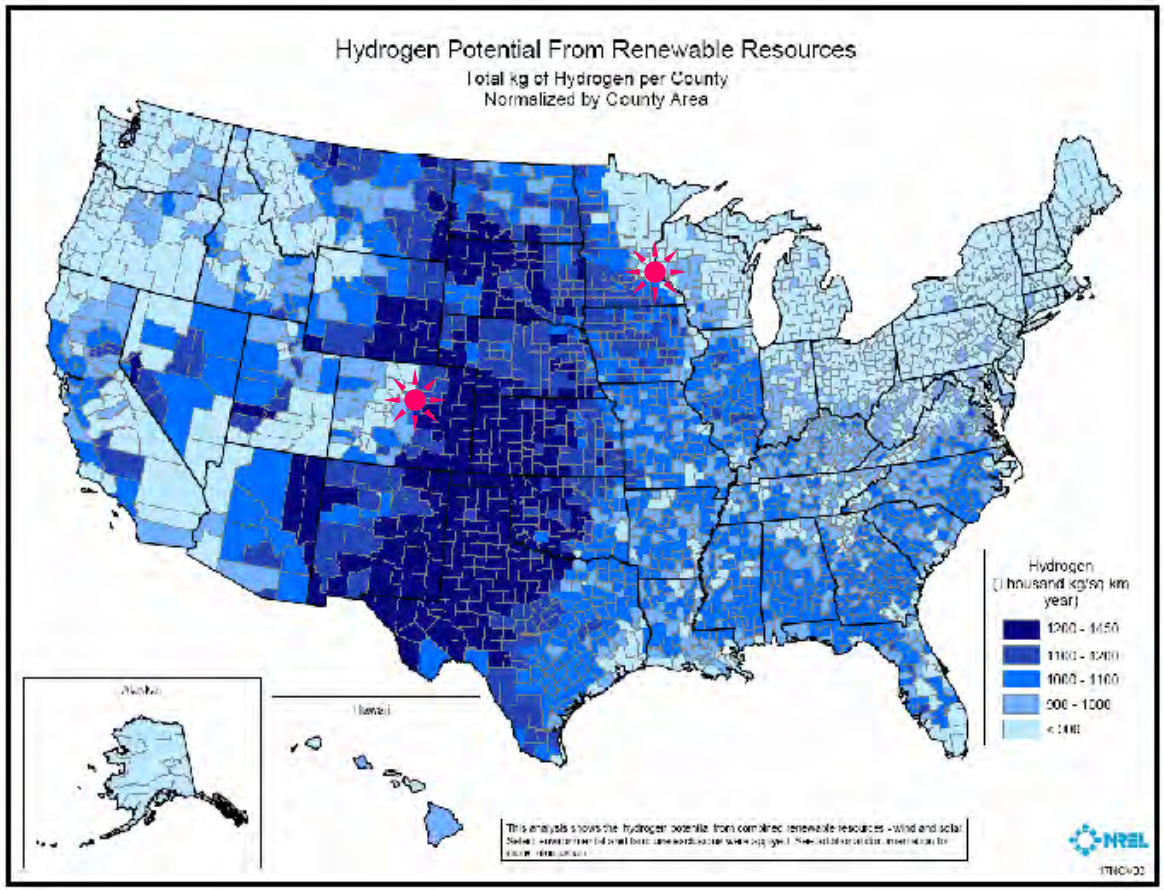


Water (H_2O)

Electricity (39 kWh/kg H_2)

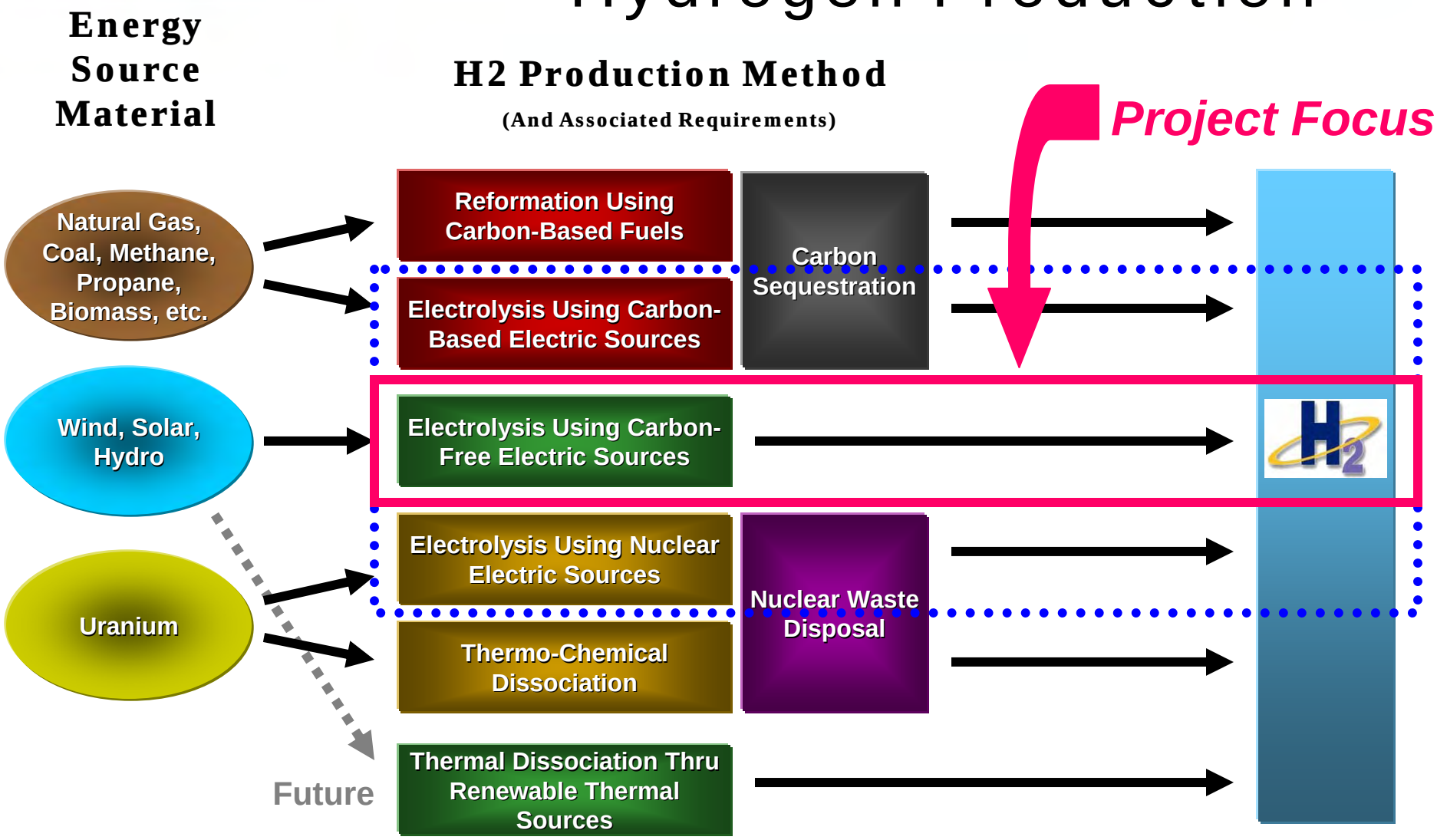
Hydrogen (H_2) and Oxygen (O_2)

Unique Opportunity?



Xcel Energy has two of the largest US population centers that are also adjacent to the best renewable energy resources in the country

Hydrogen Production



Key Question:

Is there promise for producing hydrogen from wind electricity?

Premises

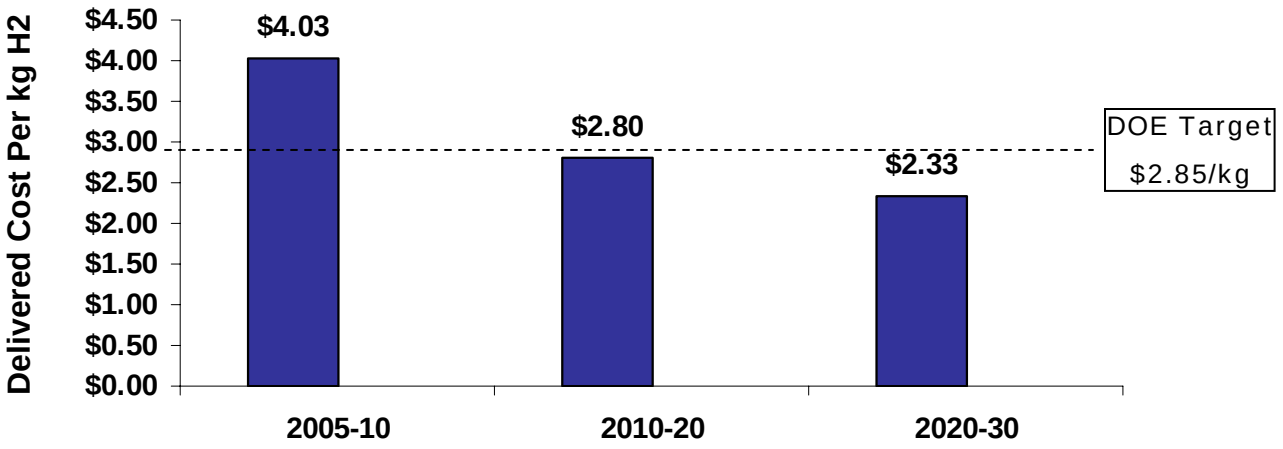
- **DOE Target: 20% of all light duty vehicles running on hydrogen by 2020**
  - **Additional electricity to supply via electrolysis: 450 terawatt-hours (*NREL*)**
  - **Existing unused off-peak electricity available (emissions aside): 368 terawatt-hours *(Accenture)***
- **DOE Target: $2.85/kg <u>delivered</u> hydrogen by 2020**
- **Renewable energy will become more attractive in the future because of cost stability and low emissions**

To Make The Case For "Renewable-Enabled" Electrolysis

- **Hydrogen from renewable energy sources must be cost competitive with other methods**
- **Electricity and hydrogen from renewable energy sources must be able to get to market**

NREL Economic Results

Hydrogen production cost analyses results



"Aggregated Xcel Energy Wind" Case for Colorado

- **Assumes $0.038/kWh wind electricity cost for all years**
- **Includes delivery costs but not dispensing costs**
- **Does not include cost benefits due to co-production of electricity and hydrogen**

Electric cost analyses not yet completed

Getting To Market

- **Existing electric transmission system constraints**
- **Energy Policy Act of 2005 - incentives and other mechanisms to facilitate transmission siting**
- **Need to better understand economics:**
  - **Transport renewable electricity and produce at point of use , OR**
  - **Electrolyze at wind site and transport as hydrogen?**

So… Is there promise for producing hydrogen from electricity?

- **<u>YES</u> – If used for vehicle fuel**

  Both "Aggregate Wind" and "Direct Wind" (local application) projections meet or beat DOE vehicle fuel price target of $2.85/kg during the next decade

- **Likely – If used for storing wind electricity**

  Electric cost analyses still being completed by NREL, and overall system benefits being investigated internally to Xcel Energy

  One of the test objectives for the demonstration

The Wind2H2E Demonstration Project

Project Concept

100 kW Wind Turbine at NREL

Electricity

Off-Peak

Water

50kW Electrolyzer

Hydrogen

Hydrogen Storage Tanks

- 85 kg
- 3500 psi

Hydrogen

for Fuel

Hydrogen

Hydrogen Engine Generator Set

Electricity

On-Peak

Xcel Energy Utility Grid

Electricity

Wind2H2E Project Features

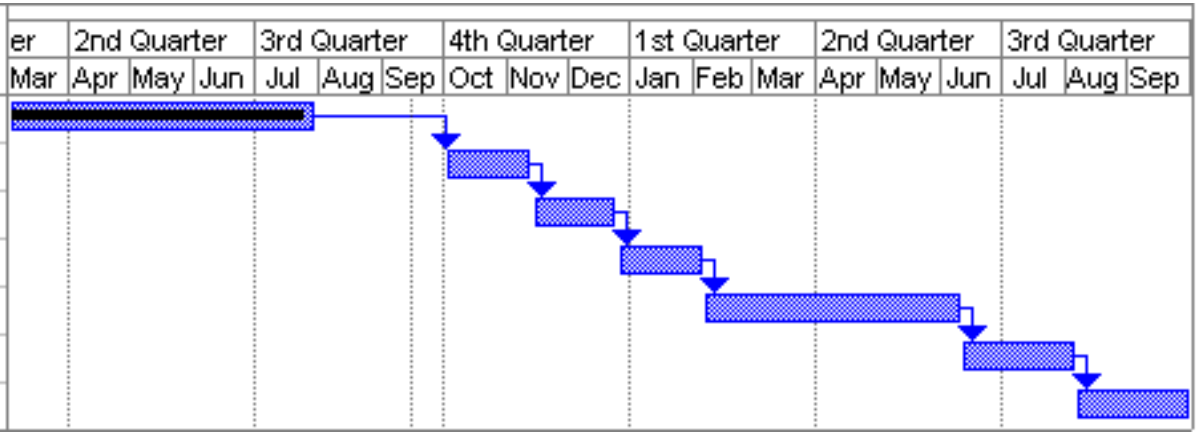
Feature	Importance
Direct DC feed to electrolyzer	System efficiency gains & future control system integration capital cost reductions
Concurrent AC feed to electrolyzer	Permits clear comparison to Direct DC feed performance
Commercial grade higher pressure electrolyzer	Reduced operability risk, system efficiency gains & reduced cost to compress hydrogen
Low/medium pressure range compression and storage	Reduced operability risk, reduced cost to compress hydrogen & improved reliability
Hydrogen ICE generator set	H2 or H2/NG mixed fuel option
Initial siting at NREL controlled facility	World class R&D practices and opportunity to learn H2 handling practices from experienced practitioners
System transportability for redeployment	Utility value after R&D testing

Resource Commitments

- **Xcel Energy to provide:**
  - **DC/DC converter, electrolyzer, compressors, storage tanks, ICE generator set, and system containment**
- **NREL to provide:**
  - **Site, wind-turbine, associated power electronics, and grid interconnections**
  - **Design and economic analysis support**
  - **Operations & maintenance of system during testing**
  - **System instrumentation, data collection and analyses**
  - **Hydrogen handling expertise and knowledge transfer**
- **EPRI, U of M, and CSU to provide expertise and support in design, component selection, and data interpretation/analysis**

Project Timeline

ID	Task Name
1	Conceptual Process Flow & Scale
2	Detailed P&ID and Process Flow
3	Detailed Mech, Elect & Civil Design
4	Equipment Specifications
5	Procurement & Equipment Testing
6	Construction
7	Startup



Demonstration Plant Scheduled For Operation
Fourth Quarter 2006

Other Hydrogen Efforts

- **Supporting University of Minnesota wind-to-hydrogen demonstration in Morris, MN**
  - **Uses output from existing 1.6 MW wind turbine**
  - **Parallel timetable to Xcel Energy/NREL project**
  - **Inter-project collaboration and data sharing**
- **Participating in formation of "Hydrogen Utility Group"**
  - **Effort supported by DOE/NREL, EPRI and the NHA**
  - **Focus on issues unique to the utility industry in the *hydrogen-electric* economy**
  - **Support development of integrated national plans and validate foundational analyses**
  - **Share knowledge & experiences**

Xcel Energy

NREL

Questions